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## Effect of Joystick Versus Control Yoke Use on Personal Computer (PC) Flight Training: A Comparative Analysis

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**EFFECT OF JOYSTICK VERSUS CONTROL YOKE USE ON  
PERSONAL COMPUTER (PC) FLIGHT TRAINING: A COMPARATIVE  
ANALYSIS**

by

**Gregory Alan Fontaine**

A Thesis Submitted to the

Office of Graduate Programs

in Partial Fulfillment of the Requirements for the Degree of

Master of Aeronautical Science

**Embry-Riddle Aeronautical University**

**Daytona Beach, Florida**

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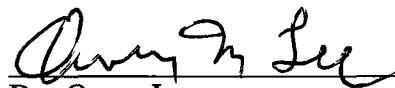
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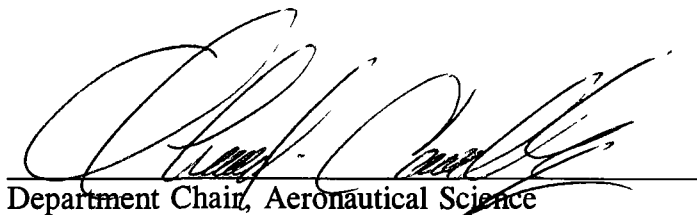
This thesis was prepared under the direction of the candidate's thesis committee chairman, Dr. Steven Hampton, Department of Flight, and has been approved by the members of his thesis committee. It was submitted to the Office of Graduate Programs and was accepted in partial fulfillment of the requirements of the degree of Master of Aeronautical Science.

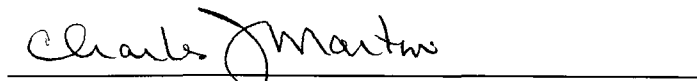
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## **ABSTRACT**

**Author:** Gregory Alan Fontaine  
**Title:** Effect of Joystick Versus Control Yoke Use on Personal Computer  
(PC) Flight Training: A Comparative Analysis  
**Institution:** Embry-Riddle Aeronautical University  
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The purpose of this study was to provide a comparative performance analysis of a generic control yoke device and a generic joystick device. The comparison provided data needed for further evaluation of personal computer (PC) aircrew training device (ATD) potential. Both devices were used in support of the same PC flight simulation software program, and were evaluated using the experimental research method. Objective and subjective data were obtained during controlled testing, and subsequently analyzed using basic summation and t-test methods. The results tested the research hypothesis that there is no significant difference in personal computer ATD operator performance using a control yoke versus a joystick device.

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## INTRODUCTION

Initial and recurrent training are an integral part of mastering nearly any skill-related task. Piloting an aircraft is an example of such a task. Since much of pilot flight training is accomplished in aircrew training devices (ATDs), effective pilot interaction with ATDs is of paramount importance. The trainee must be able to understand and comfortably use the device. User friendliness, however, is only a subgoal. The primary goal of an ATD must be to develop or support skills which transfer easily to flight in the real-world environment. Only through continued analysis of the various ATDs and all their peripherals can effective decisions be made about what is, and what is not an effective training tool.

Two of these peripherals were comparatively analyzed during this study. A control yoke device and a joystick device were used to control pitch and bank during the execution of selected basic attitude instrument maneuvers, and practice instrument landing system (ILS) approaches. The control devices were connected to a personal computer (PC) which was used to run a flight simulation software program. The entire system provides economical training opportunities for a wide range of users, all of which seek effective flight training. An effective package, however, requires selection of a flight control device which suits the situation as well as the person. Before an informed selection can be made, a question must be answered: Does one type of control device perform superior to the other?

Although the device manufacturers each have their opinions about which device is most effective, ultimate Federal Aviation Administration (FAA) certification of personal computer ATDs will require a verifiable analysis of their performance. The results of this study provide a portion of that previously unavailable data.

### **Statement of the Problem**

The purpose of this study was to compare the operational performance of two control devices when used to support a flight simulation software program. With growing interest in low cost alternatives to portions of flight training, it was evident that insufficient data existed to support informed decisions about various ATD equipment options. Two such equipment options are the control yoke device and joystick device. Throughout this paper the term "control yoke" describes a U-shaped double handle mounted to a control box. The term "joystick" describes a single vertically mounted handle. Both the control yoke and joystick devices were used for ATD pitch and bank control.

A third and fourth PC control device option existed, but they were not compared. These devices are a standard computer mouse, and keyboard. Although a mouse or a keyboard could have been used for pitch and bank control, their physical fidelity was considered too far removed from the controls used in any aircraft. Physical fidelity comparison of the control devices, however, was never the intent of this study. A functional comparison was being conducted. A comparison which includes the mouse and keyboard may be valuable for further evaluation of functional fidelity requirements of PC aircrew training devices. A literature review did not reveal any studies which specifically evaluated any of these control devices.

## Review of Related Literature

The FAA is responsible for approving aircrew training devices that will be used to meet portions of flight training hour requirements. Therefore, any new ATD which does not have FAA approval faces less potential for widespread training use. Personal computer flight simulation packages are examples of unapproved ATDs. Exact qualifications for each of the seven levels of ATDs are described in FAA Advisory Circular 120-45A (Staff, 1992, February). The FAA defends its unapproved ATD opinion of PC flight training as follows:

Because of the critical impact such devices may have on flight safety, no approvals have been granted for the use of such software packages, to date, for training under FAR [Federal Aviation Regulations] Part 61. No approval is anticipated until the capabilities of such devices have been fully explored. (Staff, 1992, January, p. 2)

Typically only devices with high physical and high functional fidelity can receive full approval for use in FAR Parts 61 (pilot certification regulations) and 141 (flight school pilot certification regulations) flight training curriculums. The personal computer ATDs, with generally accepted lower physical fidelity have, therefore, received little attention from the research community. The FAA may support the concept and extensive use of ATDs, but only after they have been fully evaluated.

One might ask why ATDs should be considered at all. If the goal is to learn to fly, what better place to do it than in the airplane? This opinion has lost much of its foundation with the development of current technology ATDs. The following excerpt from the *Operational Test and Evaluation Handbook for Aircrew Training Devices: Operational Effectiveness Evaluation* (Hagin, Osborne, Hockenberger, Smith, & Gray, 1982) offers some insight into today's ATD advantages.

Using ATDs, the instructor may proceed directly to higher level tasks if he so desires. Furthermore, the instructor can provide substantially more practice or feedback via features such as "FREEZE" and "RESET." With an ATD, moreover, the sequence of individual skills can be taught according to instructional efficiency rather than being driven by safety requirements or sequencing limitations imposed by the aircraft during flight. Thus, discriminations underlying skills can be taught in ATDs at times, and in ways, that promote more efficient development of these skills than is possible in the aircraft. (pp. 24-25)

Clearly there are advantages to using ATDs. But the FAA is not going to be convinced that ATDs warrant certification as "approved" flight training tools until questions about their physical and functional fidelity characteristics are answered. For this reason, analysis of physical versus functional fidelity requirements in the area of ATD applications is appropriate for this study. Both the underlying premise and the overall implications of this study are centered around analysis of equipment fidelity. Therefore, the terms physical fidelity and functional fidelity should be understood. Hays and Singer (1989) describe physical fidelity as including "the visual display, spatial arrangement and appearance of controls, instruments, etc" (p. 51). In other words, does the imitation appear similar to the real thing? Functional fidelity is categorized into "informational aspects and stimulus-response aspects" (Hays, & Singer, 1989, p. 51). These informational and stimulus-response aspects relate to how a person perceives and uses information gained through interaction with a device. Comparison of PC control devices requires consideration of both physical and functional fidelity.

Fidelity may affect the manner in which a person uses a device, but a true measure of ATD effectiveness is implied only by positive transfer of training to the actual aircraft. Aircrew training devices are generally accepted as being able to

provide some level of positive transfer of training. The level of transfer has been the topic of numerous studies. Transfer of instrument training is perhaps one of the most common and most tested uses of ATDs (Caro, 1972).

ATDs are often considered cost effective alternatives to long hours of expensive in-flight instruction. But ATDs offer much more than cost effectiveness. For example, they are usually much safer and more versatile than their real-life counterparts when used for training.

The cockpit of an airplane is a lousy classroom. Not only is it noisy, making lengthy conversation between student and instructor difficult if not impossible, but it is also part of an airplane that must, first of all, be flown at all times, requiring at least a certain degree of attention. Not so the simulator. (Garrison, 1985, p. 9)

Even the most rudimentary aircrew training devices can have fundamental advantages over training in the actual aircraft flight environment. Only when the goal is to precisely simulate a particular situation does the low cost ATD become the less desirable training alternative.

Physical fidelity, an often accepted requirement for any sort of ATD, at times may hinder timely and effective administration of training. One of the earliest aircraft flight training tools was a very basic three axis of movement device built in the shape of an airplane. It was called the "Antoinette apprenticeship barrel" (Rolfe & Staples, 1986, p. 16), and required two instructors to manually adjust the pitch, bank, and yaw in accordance with student induced control deflections. The attempt at physical fidelity was evident in the design which included seating position, controls, and airfoils similar to early aircraft. This design concept was continued with more advanced ATDs, such as Link Trainers (Rolfe & Staples, 1986, p. 20), which had



short wings, a vertical stabilizer, and a horizontal stabilizer. The assumption was that physical fidelity would somehow make the device more effective. Not everyone agrees with that concept. One of the first researchers to consider a possibly misdirected need for high physical fidelity was Gagné. He wrote that good training was not dependant on the need for similar tasks, but rather the need for arranging conditions which allow practice of the basic skills of the task being learned (Gagné, 1954). According to Hays and Singer (1989),

It may, in fact, be necessary to depart from realism in order to provide the most effective training. For example, the addition of instructional features, such as stop action, lesson restart, and enhanced feedback, reduce the realism of the training situation, but enhance learning. (p. 15)

There is a point, however, where extreme physical fidelity is appropriate. The most complex flight simulators have achieved a level of physical fidelity which allows them to be used in place of the actual aircraft for training. The exteriors of these devices are not designed to look like an aircraft, but everything in view of the pilot flying is carefully modeled after real-life aircraft counterparts. This level of fidelity, however, is very costly. If the task is to provide effective primary pilot training one must be careful to balance cost with performance. As Jones, Hennessy, and Deutsch (1985) point out, "small gains in realism often can be achieved only at relatively great incremental costs" (p. 27). They were referring to the exponential increase in system complexity every time a new element is added. For example, the addition of a single temperature gauge to a cockpit display sounds simple at first. But if the gauge is to read accurate it must be adjustable, which requires a variable power source or linkage, which requires a sending unit, and so forth. Where should the line be

drawn? How can one know the level of fidelity required for any given ATD training situation? Following are a few examples of research which have begun the process of personal computer ATD fidelity evaluation.

A training capability evaluation of the Cross Country Instrument Flight Trainer (CCIFT), a flight simulation software program developed by T-34 Microsystems Incorporated, was conducted at Embry-Riddle Aeronautical University (ERAU) (Connolly, Fontaine, & Landry, 1992). This independent evaluation provided the developer with expert opinion of their software program. Conclusions of the study indicated that the CCIFT has definite training potential. Experts agreed that the software could be used to reduce by 20% to 60% the time needed for training in the aircraft. Even though this personal computer ATD has very little physical fidelity, it was still considered a very effective flight training tool.

Another example of personal computer ATD application has been demonstrated by the work of Benton, Corriveau, Koonce, and Tirre (1992). They developed the Basic Flight Instruction Tutoring System (BFITS). BFITS uses a flight simulator software program in concert with an instructional module to provide detailed information about a subject's performance during training. At the same time BFITS provides a comprehensive tool for administration of the training. The simulator portion of BFITS is much like the system used for this study. It even used an identical joystick device during initial development and testing. While transfer of training research has not yet been conducted to establish the validity of BFITS, personal experience with the device quickly convinces even novice instructors of its potential.

A third ATD research example involves analysis of fidelity requirements for visual displays. Warren and Riccio (1985) used a simple altitude holding experiment to demonstrate visual cue effects. Two displays with differing levels of fidelity were used for the experiment. Subjects were tested on their ability to hold altitude using each display by itself. Subjects then used a combination of both displays to hold altitude. Experimental analysis showed that a combination of displays provided the best overall altitude control.

Warren and Riccio's report implies that sometimes more fidelity is appropriate, and sometimes less fidelity is appropriate. Regardless of which fidelity level is used, consideration of fidelity is certainly important. "The fallacy is that simulators are mere tools and lack of achievement of a tool's purpose may be due to problems in the usage of the tool rather than the quality of the tool itself" (Warren, & Riccio, 1985, p. 62). Tool fidelity makes a difference. So a question might be: If a choice must be made about which of two similar devices to use, is it best to select the one with obviously greater fidelity? Warren and Riccio's (1985) research indicates the answer is no. They "speculate that pilots trained with rich cue simulators may be unskilled with respect to weak cues. Hence they may experience difficulty if stronger cues are deleted . . ." (p. 74). The personal computer ATD's low fidelity may actually be an advantage.

The type of ATD used seems to have little bearing on its ability to supplement a training program's effectiveness. A comparative study by Hampton (1991) concluded that the performance of three different types of general aviation ATDs was such that essentially equivalent results could be obtained from each of them.

Therefore, one may deduce that if ATD type is of little consequence, then less expensive equipment may be the equipment of choice. But how can that be true? One quick comparative glance at a personal computer ATD next to a full axis simulator proves a difference in physical fidelity that must have been overcome by some greater force. A portion of that force may be the training curriculum, not the level of physical fidelity.

With highly qualified instructors (Holmes, & Hogan, 1977), and a well adapted curriculum (Caro, Isley, & Jolley, 1973), effective training can be expected in almost any type of equipment. But the question of equipment preference and comparative performance still needs to be answered. According to Stark (1979), "little attention is being given to the student's perception of the simulator, the task, or the task environment . . ." Continued and expanded evaluation of various ATD equipment options must be accomplished. Gathering subjective information about student and faculty perceptions of the ATD equipment was therefore made a subgoal of this study.

In conclusion, the aviation industry is searching for less expensive flight training equipment options. For example, United Airlines (1979, p. 139) showed an interest in low cost personal computer ATDs by funding research on their potential, and Embry-Riddle Aeronautical University (ERAU) found personal computer ATDs effective for primary instruction (Hampton, 1991). In general, the lower physical fidelity offered by personal computer ATDs is recognized as a potential money saver. However, the data needed for PC equipment validation is not available. Very few studies have been conducted. Complete personal computer ATD systems, as well as

individual system components, need to be adequately evaluated before FAA acceptance of them can be expected. This study provides a portion of the needed data by comparing two ATD control devices.

### **Statement of the Hypothesis**

Controlled testing can be used to evaluate different types of flight simulation control devices. Application of this controlled testing method will show that there is no significant difference in personal computer ATD operator performance using a control yoke versus a joystick device.

## **METHOD**

The research was conducted at ERAU using 22 flight students and six flight faculty. Objective data was collected while student subjects performed a specified set of flight maneuvers a set number of times. The maneuvers were performed using a control yoke device and a joystick device to control a PC flight simulation software program. A posttest-only experimental method of research was used to collect the objective data. Questionnaires were used to collect subjective data which the students and flight faculty provided. The following four subsections titled Subjects, Instruments, Design, and Procedures further define the method.

### **Subjects**

The target population of student subjects for this study consisted of undergraduate ERAU flight students enrolled at the Daytona Beach, Florida campus. They were approaching completion of the Instrument Certification portion of ERAU's Commercial Pilot Certification Course, and were all at the same point in their ground and flight training. All subjects had completed private pilot certification, extended cross-country requirements, commercial pilot maneuver training, basic attitude instrument training, and preliminary instrument pilot operations training. Student approximate individual total flight times ranged from 120 hours to 200 hours. The large total flight hour variation was due to flight training obtained prior to starting flight at ERAU, and due to the performance-based curriculum being used. ERAU's

exemption from the FAA's minimum flight time requirement allows for large flight hour variation from one student to the next. This variation was not considered detrimental to the study because the goal was to select a group of subjects representative of ERAU's instrument flight student population. That population had large flight hour variation. The goal was achieved.

Student ages ranged from 19 years to 26 years. The target population was composed of approximately 90% Caucasian students, of which approximately one fourth were female. A cover letter and pretest questionnaire (see Appendices A and B) were made available to 75 randomly selected students within the target population of over 180 students. The 75 students were all interested in the study and willingly completed the pretest questionnaire.

Background information on the students was gathered in part from the pretest questionnaire. Two of the pretest questions related to previous ILS experience, because a portion of the testing sequence required localizer and glide slope tracking. One student reported no previous experience with an ILS. That student received an extended briefing on what to expect during the testing. Three other pretest questions gathered information about previous PC control device experience. Five out of 22 students tested had previously used a control yoke device to control a personal computer ATD. Eight out of 22 tested students had previously used a joystick device to control a personal computer ATD.

The completed pretest questionnaires were collected and analyzed according to a selection process which step by step reduced the number of students to a fairly generic group of the required size. The goal was to select 20 to 30 students who

demonstrated minimum bias toward the control devices and the testing process.

Requiring as few as 20 subjects was within the parameters established by Gay (1990) for experimental research. Although a minimum of 30 subjects has historically been considered a standard, there are reasons to accept a lesser number. A limited amount of time available for testing, or a small population, can reduce the sample size. A reduction in funding for the research can also cause sample size reduction. According to Gay (1990),

Experimental studies with tight experimental controls may be valid with as few as 15 subjects per group. Some authorities believe that 30 subjects per group should always be considered minimum. However, considering the difficulty involved in securing subjects, and the number of studies that are reported with less than 15 in a group, requiring 30 seems to be a little on the idealistic side. (p. 115)

Another reason for sample size reduction was evident in this study. Minimum control device bias was required because the subjects were their own control. Test result validity became a primary concern. To promote increased validity, the selection process had to be very specific, which had the effect of reducing the sample size. For all the above reasons, setting the minimum sample size at 20 was considered reasonable for this study.

The sample selection/reduction process required three steps. Step one removed any questionnaires from the stack of 75 which were missing information. Step two removed any questionnaires from the remaining stack on which the student's answer to question six indicated an unwillingness to put aside any preconceived ideas about the control devices for the duration of the evaluation. Step three compared answers to questions eight and nine. These questions asked about the student's



current opinion of expected joystick device and control yoke device effectiveness when used for controlling pitch and bank on a personal computer flight simulation software program. Any students ranking the two questions differently were removed from the remaining stack of questionnaires. The theory was that students with a preconceived idea that the control devices were potentially equal would respond more accurately to posttest subjective questioning. Opinion of the two control devices would be founded more on the controlled testing sequence than on any uncontrolled prior experiences. Step three conveniently reduced the stack to 26 students. Final random selection was not required.

All 26 students were notified by telephone or note that they were selected, and that they should commit to a testing time. Testing was conducted for a two week period, during which 23 students participated. Three students were not able to arrange a testing time. One posttest questionnaire was completed backwards, so that student's results were not used in the data analysis. Results for the remaining 22 test students qualified for data analysis.

Faculty subjects for this study were six ERAU Flight Department employees currently instructing at the Daytona Beach, Florida campus. The faculty were selected for their experience with ATD instruction, and for their willingness to participate in the study.

In terms of result generalization to all aviation university flight student populations, sampling bias should be minimal. In terms of generalization to the general flying public, sampling bias may be significant due to differences from the test students' background, motivation, and training environment.

## **Instruments**

The joystick device selected for use in this study was the FlightStick. The control yoke device was the NT 360 Trainer. These control devices were used in conjunction with The Instrument Flight Trainer Professional--the flight simulation software program--which was run on a Northgate personal computer. A cover letter was distributed to promote interest in the study. Pretest and posttest questionnaires were used to collect subjective data from test subjects. A standardized data collection sheet was used to collect objective data. A practice session provided for more consistent student performance at the start of each testing session. Two similar testing profiles provided consistently sequenced testing. All of these instruments are described further in the following subsections.

**Joystick device.** The FlightStick, developed by CH Products (1987), was the joystick device selected for use during this study. It is compatible with all International Business Machines (IBM) PC/XT/AT/PS2 compatible gameports, and is available for purchase at computer stores for under \$80. The FlightStick has a contoured grip styled much like a modern aircraft's fly-by-wire system. The grip is attached vertically to a base in a way that allows it to be moved both fore and aft, and side to side for adjustment of aircraft pitch and bank attitude respectively. The device also has two activation buttons which may be used for various game applications, a small trim wheel for pitch attitude adjustment, a small trim wheel for bank attitude adjustment, and a larger wheel for power adjustment. Many selections and adjustments required for complete utilization of the computer software program must be accomplished by conventional use of the computer keyboard. Neither validity nor

reliability information about the FlightStick, when used in conjunction with a flight simulation software program, was available for this study.

**Control yoke device.** The NT 360 Trainer (NT 360), developed by NT Systems (1992), was the control yoke device selected for use during this study. It is adaptable to a variety of PC systems, and is available for purchase from the developer for approximately \$650. Selection of the NT 360 was accomplished after an informal search for other control yoke devices provided few options. One option was a control yoke device which had a very stiff feel. Small corrections were difficult to accomplish smoothly, which caused this device to be rejected. Another control yoke device option, which according to promotional literature seemed promising, could not be delivered in time for the testing. NT 360 performance was expected to be adequate for the experimentation portion of this study, and several of the units were readily available.

The control yoke portion of the NT 360 is attached to the front of a box in a fashion similar to a light aircraft's control yoke. Movement is permitted both fore and aft and side to side for adjustment of aircraft pitch and bank attitude respectively. A throttle is located at the right of the box. The front surface, or "dashboard" also includes a number of tactile feel pressure sensitive switches which may be used to simulate the basic controls found on a typical light aircraft instrument panel. Switch selection is fairly extensive. Nearly all required computer input can be accomplished using this device. Neither validity nor reliability information about the NT 360, when used in conjunction with a flight simulation software program, was available for this study.

**Flight simulation software program.** The Instrument Flight Trainer Professional (IFTP), developed by Flight Deck Software (1991), was the flight simulation software program selected for use during this study. The IFTP is a commercially produced, state-of-the-art PC flight simulation software program, and is available for purchase at computer stores for approximately \$300. The program provides the opportunity to practice simulated flight by reference to a panel of instruments, by reference to a view of ground features, or by reference to both at the same time. Every feature of a typical single-engine propeller driven airplane's instrument panel and associated controls can be simulated. Although the program has not been the subject of any validation studies, its popularity among PC users made it an appropriate choice for this study.

**Computer hardware.** A Northgate Slimline ZXP personal computer was used to run the IFTP software program during this study. This computer was equipped with an 80486 (66Mhz) processor and was connected to an NEC MultiSync 3FGx color monitor. The computer's disk operating system (DOS) was Microsoft's version 5.0. A conventional keyboard and mouse supplemented all computer input. The computer and monitor combination retail for approximately \$3,400.

**Cover letter.** A cover letter (see Appendix A) was used to solicit target population student interest in the study. The letter included information about the testing sequence, requirements for participation, and who to contact for further details.

**Pretest questionnaire.** A standardized subjective pretest questionnaire (see Appendix B) for student volunteers was used to collect information about target

population students interested in being chosen as test subjects for the study. The questionnaire was validated by three ERAU Flight Department faculty members. Each faculty member was personally interviewed after they had the opportunity to review the draft copies of the questionnaire. Revisions were made as needed. The information and opinions collected by the questionnaire were determined to be useful student selection criteria, and current student opinion. The faculty agreed that, in combination with the cover letter, the potential test subjects could be effectively screened and selected, ultimately providing a reliably homogeneous, relatively unbiased test subject population.

The pretest questionnaire was developed by the author of this document for the express purpose of the study. Student name, ERAU mailbox number, age, present flight course designation, approximate total flight hours, and telephone number were recorded at the top of the form. Five questions were used to gather information about the student's background experience. One question asked about the student's willingness to put aside any preconceived opinions about the control yoke and joystick devices for the duration of the testing. Four statements at the bottom of the questionnaire requested student opinion of control device effectiveness, and computer familiarity. These statements were presented in Likert format, each of which required the student to mark on a scale of one to five an opinion of the statement. The student's four responses were later used for comparison with posttest questionnaire responses.

**Testing equipment setup sheet.** The testing equipment setup sheet (see Appendix C) was used to insure a consistently configured flight simulation software

program. The intent was to have every student volunteer experience identical instrument indications and situations. Initialization parameters for each segment of the testing sequence were chosen for their ease of application to the software program, and for their ease of reference by the student during simulated flight. These parameters included geographic location, altitude, heading, airspeed, power setting, and trim.

**Testing profiles.** Two different testing profiles (see Appendix D) were used to provide consistent maneuver sequencing, and to provide adequate opportunity for data collection of target population students. The profiles were developed by the author of this document for the express purpose of the study. Two versions of the profile were used so as to allow consideration of, and to minimize, any control device sequencing bias. The maneuvers and maneuver sequence were selected for the variety of skills they required of the pilot, and for their ease of evaluation.

The profiles were used in a fashion similar to a checklist. The evaluator followed the profile instructions step by step until their completion. The student was first given a brief overview of the testing sequence, and acclimated to the testing equipment. Then a two minute practice session using each control device was provided. The practice session was developed by the author of this document for the express purpose of the study. Two different practice sessions were used to provide the student an opportunity to become familiar with the testing equipment, and to establish a comfortable instrument crosscheck. The only difference between the two practice sessions was the sequence in which each control device was practiced. Profile A students practiced using the control yoke device, then using the joystick

device. Profile B students started out using the joystick device, then switched to the control yoke device. Both practice session sequences were otherwise identical.

The student was directed to accomplish straight and level, turns, and pitch changes for approximately two minutes. The aircraft position was reset and the same sequence followed using the other control device. No data was collected during the practice sessions, and no particular performance standards were required. The practice session sequences were validated by three ERAU Flight Department faculty for effectiveness of crosscheck and control device practice. The faculty expected that very little bias would be introduced by the duration and content of the practice, and that the students would be reliably prepared for the testing session. Further validation of the practice session sequences was accomplished by performing three test runs using student volunteers. The practice session sequences adequately prepared the volunteers for the testing session maneuvers using each control device.

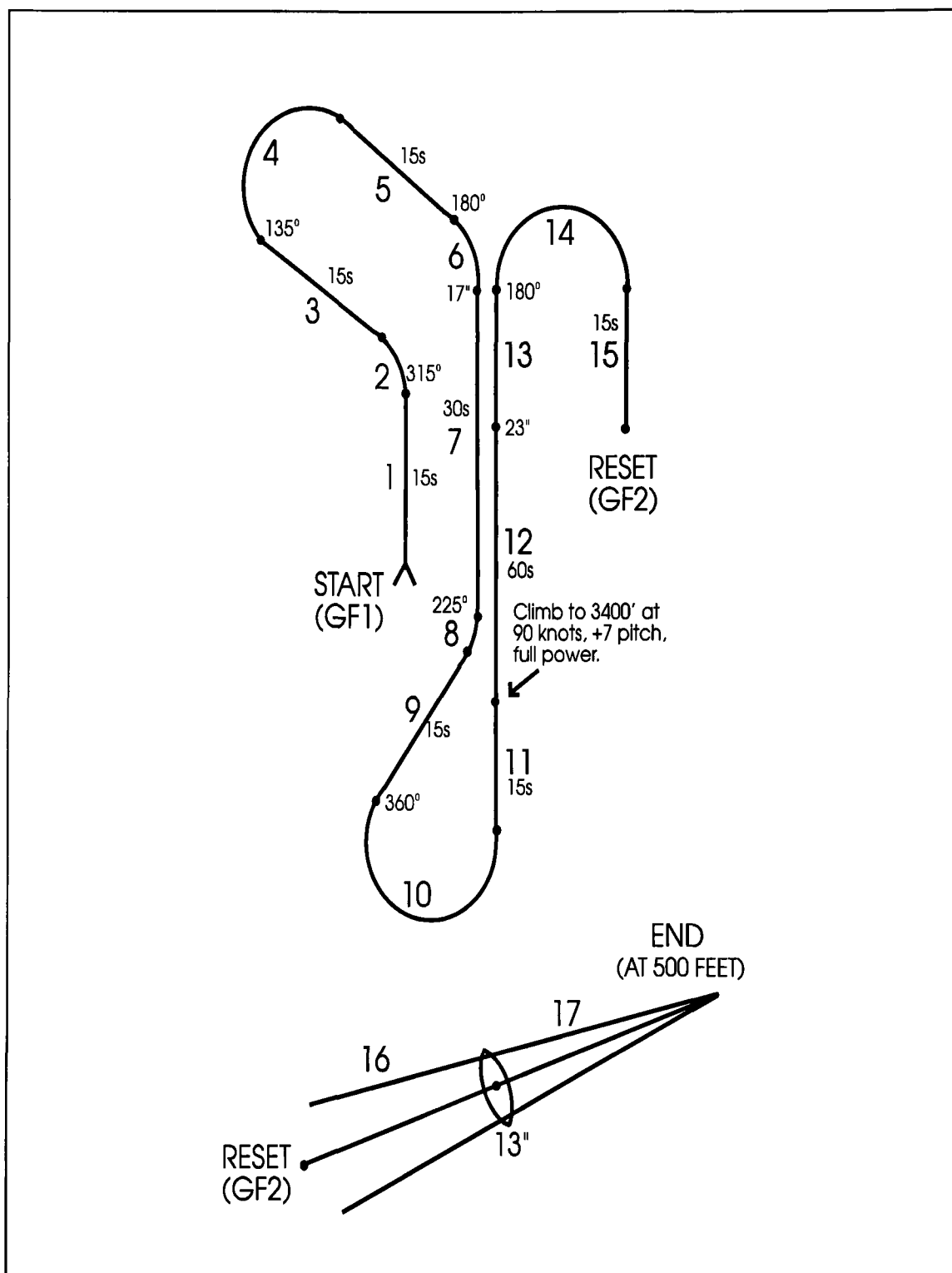
Immediately after the practice session the student was guided through a basic maneuver sequence using both of the control devices. The basic maneuver sequence started from a heading of 360 degrees. However, the standard initialization location placed the aircraft on a heading of 068 degrees. This disparity was intentional. Starting on the 068 degree heading gave the student the opportunity to stabilize the aircraft before data collection was begun. During test runs it was found that bypassing this brief stabilizing step had a tendency to promote artificially large pitch and bank variations during the first portion of each testing segment. After the student stabilized the aircraft on the 360 degree heading, the basic maneuver sequence and data collection were begun. The entire maneuver sequence was completed

uninterrupted except for the few seconds it took to reset location from GF1 to GF2 in preparation for the ILS portion. The terms GF1 and GF2 signify preprogrammed aircraft locations and configurations.

Figure 1 shows the basic maneuver sequence which was used throughout the testing. The solid line depicts the path over which the student is directed. Small dots overlapping the solid line indicate start and finish points of each segment. The start of each segment is annotated with instructions for the proper execution of the segment. Each segment is marked with a large number which sequentially corresponds with the numbered segments of the data collection sheet. The small numbers associated with each straight segment indicate the length of time in seconds which would pass before starting the next segment.

The basic maneuver sequence was developed specifically for this study with four goals in mind. First, the sequence had to be repetitious enough to provide the opportunity for similar segment comparison. Six turns and seven straight and level flight segments provided this repetition. Second, the maneuvers had to be fairly simplistic so as to not introduce student skill deficiency errors into the results. More complex maneuvers, such as stalls or slow flight may have become a challenge in themselves. The students might therefore experience procedure-induced exaggerated control deflections which were not related to the particular control device in use. Third, the sequence needed to have at least one segment which would require more discriminating pitch and bank control without being overly complex. This segment was required because, during preliminary sequence development, it was noted that a few students needed a more challenging task to look forward to. An ILS segment





**Figure 1.** Basic Maneuver Sequence used for Profiles A and B.

was added. The result was that student concentration levels appeared to remain more consistent throughout the testing session. Fourth, the sequence had to be completed in less than 15 minutes so the students would not become overly fatigued or bored with the process, and to allow the entire session to be completed within a standard 50 minute time block. These time constraints provided up to ten minutes for the student briefing and practice session, 15 minutes for testing control device A, 15 minutes for testing control device B, and ten minutes for completion of the posttest questionnaire. All four goals were achieved.

At the completion of the flight portion of the profile, the student was asked to complete a posttest questionnaire. The posttest questionnaire is described in subsequent paragraphs.

The testing profiles were validated by three ERAU Flight Department faculty for effectiveness of control device evaluation, and for efficiency of data collection. Validation was accomplished by brief practice on the ATD, and by personal interview. The faculty expected use of the testing profiles would allow a student's control input to be systematically and reliably exercised, providing an adequate foundation for control device comparison. Further validation of the testing profiles was accomplished by performing three test runs using student volunteers. During the test runs the testing profiles appeared to adequately achieve their expected purpose of control device evaluation, and data collection efficiency.

**Data collection sheet.** A data collection sheet (see Appendix E) was used to record objective performance data obtained during student execution of the testing profiles. The data collection sheet was developed by the author of this document for

the express purpose of the study. An area at the top of the data collection sheet provided room for a student reference number, the control device designation, the current date, the testing start time, and the testing stop time. Each sheet was also annotated with the applicable testing profile letter. The remainder of the sheet was a table which included an area to record student performance during all 17 segments of the appropriate maneuver sequence. The specific categories of data to be recorded were altitude, heading, airspeed, bank, rollout, pitch attitude, localizer needle deflection, and glide slope needle deflection.

Using the data collection sheet to record data required an understanding of the exact moment each segment of the profile began and ended, and how the data within each collection category was intended to be measured. The basic maneuver diagram (see Figure 1) was used to indicate the start and finish of each segment. A small dot was used to indicate the beginning and end of each segment. When a dot was shown preceding a turn, the data collection for the turn segment began the moment a bank for the turn was initiated, and ended the moment the turn was completed as determined by a wings level attitude. Any post-turn oscillations were included within the subsequent straight and level segment. For the climb segment (see segment number 12, Figure 1) data collection began immediately after climb speed was first achieved or stabilized, whichever occurred first, and ended the moment pitch attitude was adjusted to begin level-off. The straight and level segment preceding the climb segment ended with initial pitching up for the climb entry. The straight and level segment subsequent to the climb segment began immediately after level-off altitude was achieved or stabilized, whichever occurred first. Data collection for the glide

slope segment (see segment number 17, Figure 1) began the moment the glide slope needle was centered or stabilized, whichever occurred first. Glide slope data collection ended upon reaching an altitude of 500 feet, or upon achieving a full scale deflection of the glide slope needle.

The data within each collection category was intended to be measured as consistently as possible. The following rules for data collection were used throughout the study for all test subjects. Altitude variation was measured using 50 foot increments from the assigned altitude to the largest altitude variation during the segment. When a new segment began at an altitude other than the assigned altitude (because of student error) the measurement was taken relative to the new altitude. If the student chose to return to the originally assigned altitude, measurement was again referenced to the assigned altitude. Heading variation using five degree increments was measured and recorded in the same manner as altitude variation. Airspeed variation was measured using five knot increments from the assigned airspeed to the maximum variation during the segment. Bank variation was measured using five degree increments from the maximum to the minimum bank angle observed during the segment. Data collection started the moment a standard rate turn was achieved or stabilized, whichever occurred first. Bank data collection ended at initial recovery to straight and level. Rollout variation was measured using five degree increments from the assigned heading to the heading observed during the first rollout attempt. Pitch attitude variation was measured using five degree increments from the maximum to the minimum pitch attitude observed during any single pitch attitude oscillation during the segment. Localizer needle variation was measured using either 1/4, 1/2, 3/4, less

than full scale, or full scale deflection from the center. The maximum deflection observed during the segment was recorded. Data collection began the moment the localizer needle first centered itself during aircraft relocation. Glide slope needle variation was measured from the centered position using either 1/4, 1/2, 3/4, less than full scale, or full scale deflection. The maximum deflection observed during the segment was the one recorded.

The data collection sheet was validated by three ERAU Flight Department faculty for efficiency, accuracy, and evaluation of data collection. Validation was also accomplished by performing three test runs using student volunteers. During the test runs the evaluator was able to use the sheet as intended. The selection of data collection categories, and the design of their associated increments was influenced by data collection sheets used during another ERAU study of PC aircrew training device equipment (Hampton, 1993). Success of the similar sheet used by Hampton's study therefore offered an indication of validity and reliability to the data collection sheets used during this study.

**Posttest questionnaire.** A standardized subjective posttest questionnaire for student volunteers (see Appendix F) was used to collect target population student opinion of each control device. A similar postpractice questionnaire (see Appendix G) was used to collect faculty opinion of each control device. Both questionnaires were developed by the author of this document for the express purpose of the study. The description that follows specifically addresses the student posttest questionnaire, but may also be applied to the faculty postpractice questionnaire. The only difference between the two questionnaires was the title and general heading information.

The posttest questionnaire provided an area at the top for a student name, and the current date. Each sheet was also annotated with the applicable testing profile letter and student reference number. The remainder of the questionnaire included 12 statements presented in Likert format, each of which required the student to mark on a scale of one to five an opinion of the statement.

The posttest questionnaire was validated by three ERAU Flight Department faculty members for effectiveness and efficiency of subjective data collection. The faculty agreed that the posttest questionnaire would provide a reliable, measurable, and comparable indication of student opinion about the control devices they would have finished using a few moments earlier.

### **Design**

The posttest-only experimental method of research (Gay, 1990) was used to provide a performance comparison of the two control devices. This method evaluates cause-and-effect relationships by using a controlled experiment. The person responsible for data collection is not a direct participant in the experiment. The person only observes and records data. For example, during student and faculty testing for this study the observer was able to remain detached from, and undistracted by, the demands of actually flying an aircraft. This detachment permitted more consistent data collection than would otherwise be possible.

The method also provided an unexpected advantage. Throughout the course of data collection it became apparent that a previously considered, but later rejected, "automatic" data collection software program would not be able to evaluate control device performance as well as a single observer. Although the data collection

software program would more consistently record precise flight parameter statistics, it would not be able to filter out any deviations caused by unrelated occurrences. Several examples of these occurrences were noted during the testing. On occasion students would reposition themselves in the chair, causing sudden and artificial maneuver deviations. At other times the students would sneeze or simply divert their attention from the task at hand. Again these actions caused artificial deviations. The observational method permitted disregard for the momentary deflections. An "automatic" data collection software program would have recorded these artificial deviations, thereby contaminating the test results.

Two variables needing the most control were observer and subject bias. Observer bias was controlled by using only one person to collect all objective performance data from two standardized maneuver profiles. Valid and reliable data collection was further supported by the observer being a subject matter expert. Subject bias was minimized by using students with comparable ages, ground training, simulator experience, opinions, and motivations, as determined by the pretest questionnaire. Flight faculty subject bias was reduced by providing structured control device practice immediately preceding the subjective postpractice questionnaire. The students and flight faculty were their own control. They performed identical tasks using the control yoke device and the joystick device.

Potential invalidity sources--such as history, maturation, testing, instrumentation, regression, selection, and selection interaction--are naturally compensated for by virtue of the experimental method. External invalidity--pretest interactions and multiple treatment interference--would likewise pose minimal threat

by design of the method. The one threat not automatically controlled by the selected research method was subject mortality. However, since each subject required only one brief treatment, a missed appointment could be rescheduled or an alternate subject could take their place.

The independent variables being manipulated were use of two different control devices. The dependent variables were the comparative measure of pilot objective performance and subjective opinion of each device. Table 1 offers a visualization of the method. Two groups of 11 subjects were both randomly and selectively formed. Group A (control yoke device first) was assigned maneuver profile A. Group B (joystick device first) was assigned maneuver profile B. Data was collected from both groups by recording observed performance, and by completion of questionnaires.

**Table 1**

**Posttest-Only Experimental Method Detail**

<b>Group</b>	<b>Assignment</b>	<b>Number</b>	<b>Maneuver Profile</b>	<b>Data Collection</b>
A	Random and Selective	11	A	Questionnaires and Observed Performance
B	Random and Selective	11	B	Questionnaires and Observed Performance

Factors that made the posttest-only experimental method the most effective for this study were (a) random subject selection, (b) little requirement for a pretest, (c) manipulation of the independent variables, (d) control of most invalidity sources, and



(e) use of a control group. Basic summation of the subjective data was also conducted. It was expected that the combination of objective and subjective data would provide a more complete control device comparison than would otherwise be possible by using only objective data.

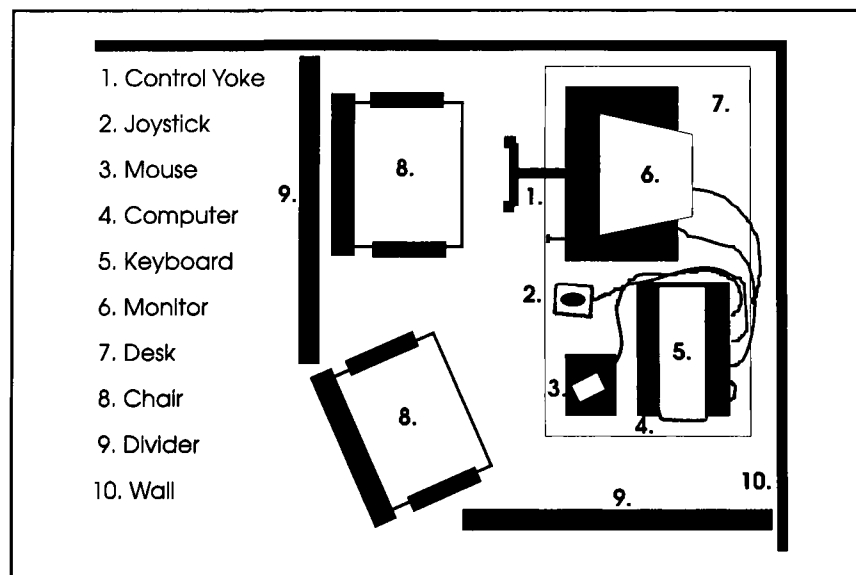
Limitations to this study relate to result generalization potential, extreme content specificity, and uncontrolled external variables. Result generalization is limited to flight university students with primary instrument training already completed. The motivations, background, and flight training experiences of students differing from this group would add variables not considered by the study. Extreme content specificity was caused by evaluation of only one feature of one personal computer ATD component--the control device. Evaluation of only basic flight maneuvers further narrowed the testing content. When that which is tested includes a relatively small portion of the total training situation, result generalization is likely to be reduced.

Uncontrolled external variables can also limit result generalization. One such variable during this study was the abundance of aircraft control yoke experience. All the student test subjects trained using aircraft equipped with control yokes. This fact may have unknowingly provided a foundation for expected ATD control yoke device performance. Similar aircraft joystick experience was not available. Therefore, it is possible that aircraft joystick inexperience provided no real-life basis for comparison, which left more room for ATD joystick device opinion variation. Overall subjective opinion of the ATD control devices may have been skewed in favor of the joystick device.

## **Procedure**

The testing area and all required testing equipment were reserved for approximately 60 days. The room which contained the selected testing area was designed for PC flight training analysis and student tutoring. The immediate testing area was partitioned off with soundproofing dividers. Only the test subject and evaluator were permitted in the testing area so as to minimize test subject distraction and associated performance irregularities. Figure 2 depicts the testing area layout.

The computer, keyboard, mouse, monitor, joystick device, and control yoke device were all arranged to provide easy access. All components of the system were connected and configured to allow simultaneous operation. Approximately four hours were spent practicing with the equipment to insure the system would perform as expected, and to gather information about potential maneuvers for the practice and



**Figure 2.** Testing Area Layout.

testing sequences. Pitch and roll rates of both control devices were adjusted to similar values. Two start-up locations were entered into the software memory, and saved as files named GF1 and GF2.

The practice and testing sequences were developed. Three volunteers assisted with equipment and maneuver sequence pretesting to confirm that there existed no problems with the equipment or timing. Only minor timing modifications were made. Three faculty members reviewed then validated the practice and maneuver sequence as an appropriate tool for collection of data relevant to pitch and bank control.

Two instrument ground training classes were randomly selected to provide the sample student population from which test subjects would be selected. A brief presentation on the purpose and conduct of the study was given to both classes. The intent was to promote interest in the study, and to motivate students to participate. At the end of each presentation all the students in the class were given a cover letter and a pretest questionnaire. Those students desiring not to participate in the study were instructed to leave the sheet blank. Sheets were collected immediately after being completed.

The test subject selection process began after all pretest sheets had been collected. Three steps were required. Step one disqualified those students that did not properly complete the pretest questionnaire. This step disqualified two students. Step two disqualified those students that said they would not be willing to put aside any preconceived ideas about the control devices for the duration of the evaluation. This step disqualified one student. Step three compared each student's answers to questions eight and nine. Those students ranking the two questions differently were

disqualified. Step three reduced the qualified students to 26. This number was within the range of desired students for the testing. Final random selection was not required. Each qualified student was randomly assigned one of the two maneuver profiles. The profile letter was annotated on the student's pretest questionnaire.

The 26 students selected for testing were notified by phone or note, and asked to arrange a convenient one hour time block for testing. A schedule was developed, and testing began. Testing was scheduled an average of three times a day from 11:00 a.m. to 4:00 p.m., and was completed within a nine day period.

Test subjects arrived at the testing area at their appointed time, and were seated directly in front of the control yoke device and computer monitor (see Figure 2). All books, backpacks, and other equipment the students brought with them were placed behind the divider, clear of the testing area. The evaluator was seated in front of the computer and keyboard with a data collection notebook which included the practice sequence, maneuver sequence, student pretest questionnaire, a blank posttest questionnaire, and data collection sheets.

The student's pretest background information was reviewed and updated with the student, and a reference number and profile letter annotated on each sheet to be used for the student's testing. Reference numbers were assigned sequentially with the first student receiving number one and the last student receiving number 22. Then the assigned profile (see Appendix D) was started with a brief period of practice. The practice session was strictly controlled so as to minimize the chance of it biasing the test session. After practice was completed on both control devices, the aircraft location was reset to GF1, and the maneuver sequence was begun. The profile and

maneuver sequence were strictly adhered to. A data collection sheet (see Appendix E) was completed in its entirety for each control device.

A posttest subjective questionnaire was completed by the student immediately following the simulated flight portion of the testing. The student's name was printed at the top of the form, the current date entered, and a response made to every item on the questionnaire. Once completed, the student was informed that their testing was finished, and that they would receive information in the mail describing the results of the study.

Before any analysis of the results began, six ERAU flight faculty were asked to participate in the study. Each of the faculty had over ten years of primary and advanced training, and evaluation experience. Most of their simulator experience was gained while teaching or evaluating flight students using Link, Frasca 141, Frasca 242, and Frasca 242T flight simulators. None of the faculty volunteers had extensive experience teaching in PC aircrew training devices.

At an agreed upon time each faculty member was seated in front of the control yoke device and monitor. They were told that the study was a comparison of the effectiveness of the control yoke and joystick devices when used to control pitch and bank on the PC, and that they would be given a brief period of practice using each control device. The faculty were also briefed on the practice session's sequence of events. The first three faculty were tested using the control yoke device, then the joystick device. The last three faculty were tested using the joystick device first, then the control yoke device. Each faculty volunteer was guided through the same basic practice sequence used on the student subjects. The faculty volunteer was then

provided the opportunity to accomplish a few extra maneuvers at their discretion. After the same sequence was completed using each control device, the practice was terminated. The faculty volunteer then completed a postpractice subjective questionnaire with the same questions as those found on the student posttest questionnaire. All six faculty volunteers completed the practice session on the same day. Each session lasted approximately ten minutes.

Summation of the data was started after all testing and practice was completed. Both subjective and objective data were summarized using tables. Analysis of the data was then started. The subjective data was presented in graph form so as to allow easy summation and analysis. Data from the faculty postpractice questionnaire was compared to student posttest data. Analysis of the objective data was accomplished using the t-test method for nonindependent samples.

The assumptions made in reference to the experimentation portion of this study were that (a) each of the students would remain motivated to perform with a consistent level of intensity throughout the testing, (b) no extra practice would be permitted prior to the practice and testing sessions, and (c) the practice and testing profiles would be strictly adhered to. The primary limitation of this study was that the results would not necessarily reflect the actual effect either of the control devices may have on transfer of training to a real aircraft. However, sufficient data was collected to justify this study being used in conjunction with a larger, more comprehensive and generalizable PC flight simulation transfer of training study.

## ANALYSIS

It was anticipated that the results of this study would support the research hypothesis that there is no significant difference in personal computer ATD operator performance using a control yoke versus a joystick device. The belief was that successful support of the hypothesis would be valuable to the furtherance of PC acceptance as a valid, low cost aircrew training device. If the data analysis conclusions did not support the research hypothesis then three considerations would arise. First, an investigation into the possible intrusion of significantly uncontrolled internal or external variables would have to be made. Existence of such variables may require voiding the results altogether. Second, the conclusions could imply significantly better performance by the control yoke device. This result would mean that personal computer ATDs may need higher physical fidelity equipment than typically used if they are to be considered valid FAA approved aircrew training devices. A need for high physical fidelity could also place the system cost at a level considered prohibitive by the typical flight student. The third possible result of the conclusions could be that the joystick device exhibited significantly better performance than the control yoke device. This result might be unexpected because of the comparatively inferior physical fidelity of the joystick device to a typical light trainer aircraft. However, such a result would keep system cost at a minimum, permitting easier acquisition by individuals and groups alike. Superior performance by the

joystick device would also promote acceptance of the basic concept of PC training for its functional fidelity, and not for its limited physical fidelity.

Objective data was gathered for eight categories of flight control. These categories were altitude variation, heading variation, airspeed variation, bank variation, rollout variation, pitch variation, localizer variation, and glide slope variation. Control yoke and joystick device objective performance means were calculated and compared for each of the flight control categories (see Appendix H). A t-test for nonindependent samples was used to evaluate significant difference at the .05 significance level. In order for the t-test to demonstrate no significant difference, the value at 21 degrees of freedom needed to be less than 2.080. For comparison purposes the t-test value would have needed to be less than 2.831 at the .01 level of significance, and less than 3.819 at the .001 level of significance. Table 2 shows the t-test results for each of the eight flight control categories.

Both bank variation and pitch variation categories indicated t-test values which were greater than the .05 level of significance of 2.080. Bank variation and pitch variation therefore showed a significant difference between the performance of the control yoke and joystick devices. The hypothesis had to be rejected. The other six flight control categories did not show a significant difference between the performance of the control yoke and joystick devices. Six values supporting the hypothesis were not enough. The hypothesis would have been rejected if only one of the flight control categories showed a significant difference. Hypothesis rejection was further supported by the relative extremity of these two t-test values, and the importance the associated flight control categories maintain relative to the other categories.



**Table 2****Flight Control Category t-Test Values**

Category	t-Test Value
Altitude Variation	0.42
Heading Variation	1.00
Airspeed Variation	1.72
Bank Variation	3.06
Rollout Variation	0.50
Pitch Variation	5.79
Localizer Variation	1.00
Glide Slope Variation	0.50

Objective data collected during the testing sequences provided sufficient data for analysis of the hypothesis. However, in order to evaluate operator performance of either control device, subjective data was needed. This data was provided by the student pretest and posttest questionnaires (see Table 3). Two of the pretest questions gathered information about the student's experience with ILS approaches.

Performance comparison of students with varying levels of ILS experience showed no indication of ATD control difficulties during the ILS segments. Three other pretest questions gathered information about the student's previous control device experience. Only five of the 22 students indicated previous experience with one of the evaluated control devices and not the other. There was concern that these five students might

**Table 3****Summary of Subjective Pretest and Posttest Student Responses**

Subject Number	Profile Letter	Device (see note)	Pretest Question			Posttest Question						
			A	B	C	A	B	D	E	F	G	H
4	A	CY	4	2	4	5	1	3	1	4	4	4
		JS			4			5	5	1	2	3
6	A	CY	4	2	3	4	1	2	2	2	4	5
		JS			3			5	3	3	2	2
8	A	CY	3	3	3	4	1	5	3	2	2	4
		JS			3			5	3	2	2	4
9	A	CY	2	2	4	4	1	4	2	2	4	2
		JS			4			4	4	2	2	2
10	A	CY	3	2	5	2	1	4	3	4	4	4
		JS			5			4	3	2	2	4
11	A	CY	4	3	4	3	2	4	2	3	3	4
		JS			4			5	5	1	1	3
13	A	CY	5	1	5	5	1	4	1	5	4	2
		JS			5			5	5	1	1	1
15	A	CY	4	2	3	4	1	4	2	2	3	5
		JS			3			5	4	2	3	4
16	A	CY	3	4	4	4	4	4	2	2	4	4
		JS			4			4	4	2	3	4
20	A	CY	4	2	5	4	2	2	1	4	4	5
		JS			5			5	5	1	1	1
22	A	CY	4	5	5	4	2	4	5	1	2	2
		JS			5			2	1	4	5	3
1	B	CY	5	3	5	5	1	4	2	4	4	4
		JS			5			5	5	1	2	3
2	B	CY	5	2	4	4	1	4	4	2	2	3
		JS			4			4	2	2	4	4
3	B	CY	4	3	4	4	3	3	2	5	4	4
		JS			4			4	1	2	2	3
5	B	CY	4	1	4	4	1	3	2	3	4	3
		JS			4			4	5	1	2	2
7	B	CY	5	2	4	4	2	2	1	5	4	5
		JS			4			5	5	2	3	2
12	B	CY	5	4	4	4	3	4	4	4	2	2
		JS			4			4	2	2	2	3
14	B	CY	4	4	4	4	2	4	4	2	2	2
		JS			4			4	2	2	4	2
17	B	CY	3	2	4	4	2	4	2	2	4	4
		JS			4			4	5	2	1	4
18	B	CY	4	3	4	3	3	5	2	5	4	3
		JS			4			5	4	1	1	4
19	B	CY	4	3	4	4	2	3	2	4	4	3
		JS			4			4	4	2	1	2
21	B	CY	5	4	4	5	2	4	3	4	4	4
		JS			4			4	3	2	2	2

Note. Device not applicable to questions A and B, Control Yoke (CY), Joystick (JS).

A = Your current level of familiarity with computers allows you to use one without apprehension.

B = A mouse device is likely to be effective for controlling pitch and bank on a PC flight simulation software program.

C = The CY/JS is likely to be effective for controlling pitch and bank on a PC flight simulation software program.

D = The CY/JS is effective for controlling pitch and bank on a PC flight simulation software program.

E = The CY/JS quickly became my preferred control device for use during general maneuvering.

F = The CY/JS made small pitch and bank adjustments difficult to perform.

G = The CY/JS on occasion became distracting because of its poor overall control feel.

H = The CY/JS needs to provide a more realistic simulation of expected control pressures.

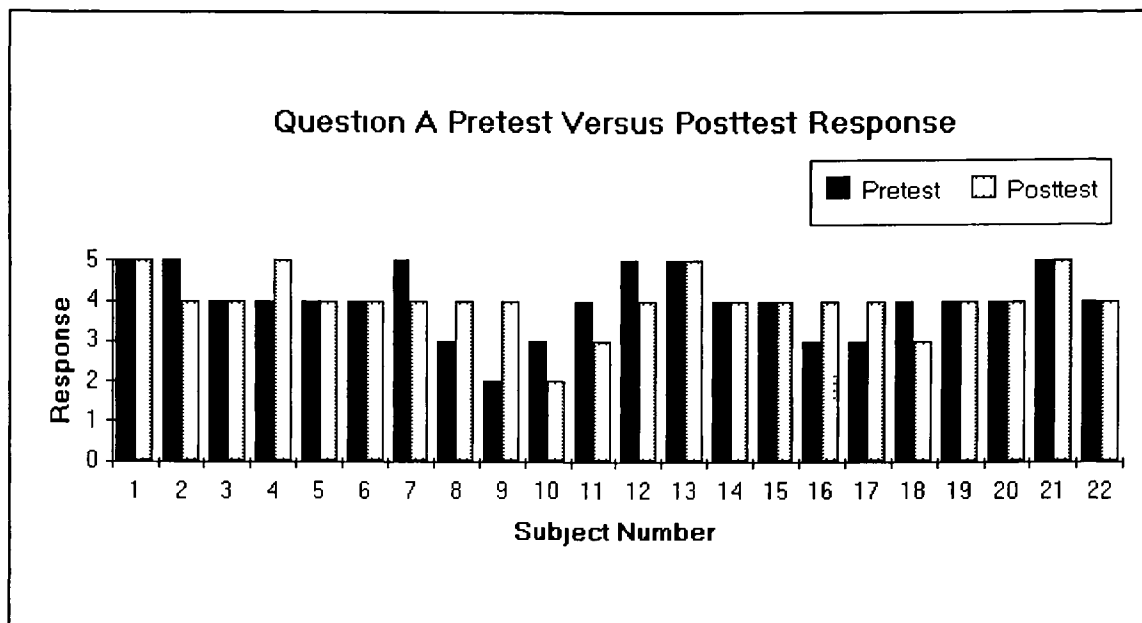
1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.

favor the control device on which they had the most experience. However, comparison of the objective test results, and comparison of the subjective questionnaire results showed no indication of control device preference being linked to previous control device experience.

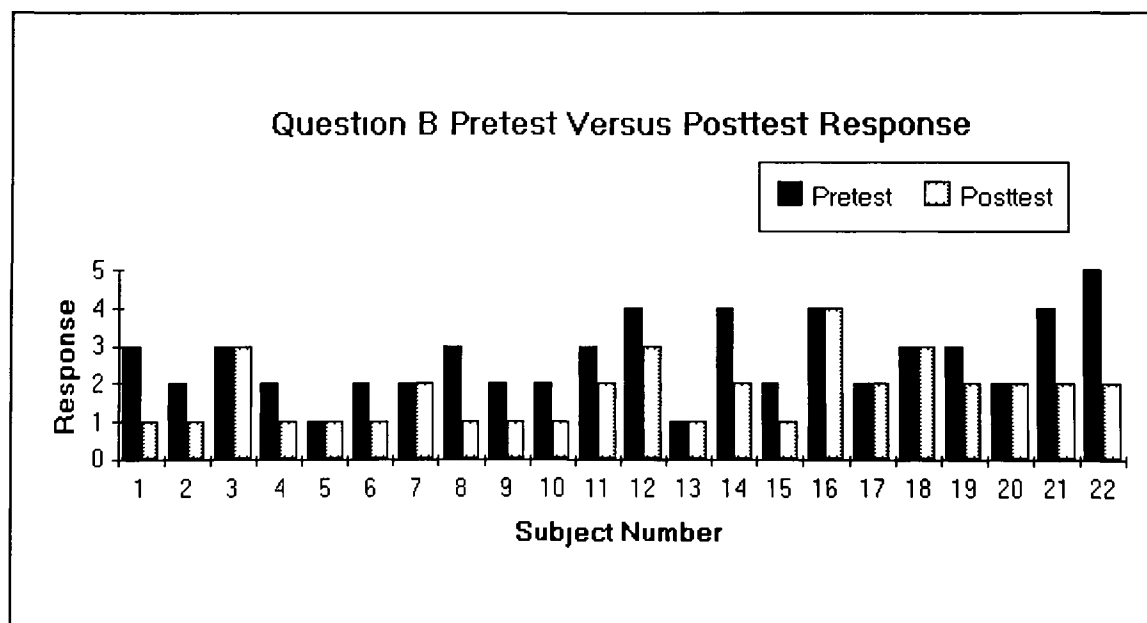
Figures 3 through 10 offer pictorial summations of responses for each of the eight main questions asked. Within each figure the vertical numbers one through five indicate student response to the titled question. Response one indicates "Strongly Disagree," response two indicates "Disagree," response three indicates "Neutral," response four indicates "Agree," and response five indicates "Strongly Agree."

Question A was included on both the pretest and posttest questionnaires. The question stated, "Your current level of familiarity with computers allows you to use one without apprehension." The purpose of this question was to provide a measure of consistency to the questionnaires. Since the time span from pretest to posttest was never more than 16 days, minimum variation of responses was expected. Figure 3 compares the pretest to the posttest responses to this question. Only one student varied more than one response level. Consistency was evident.

Question B was included on both the pretest and posttest questionnaires. The question stated, "A mouse device is likely to be effective for controlling pitch and bank on a PC flight simulation software program." The purpose of this question was to provide an indication of student opinion variation caused by testing of other control devices. It is clear from Figure 4, which compares the pretest to the posttest responses to this question, that general opinion of the untested mouse device degraded after testing of the other two control devices. This degraded opinion may have been



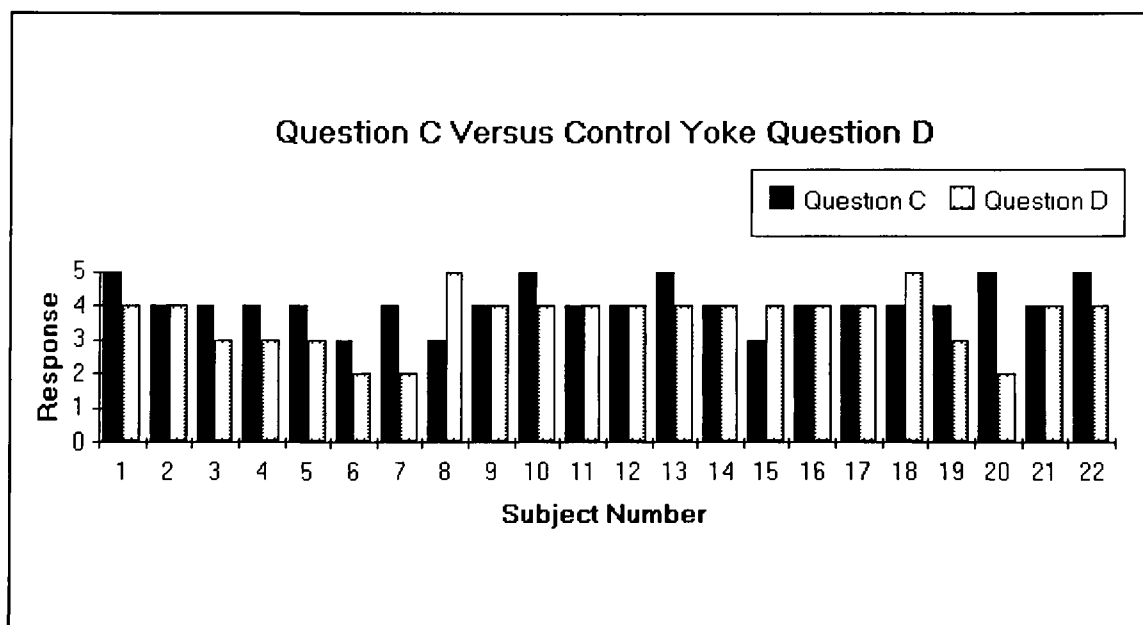
**Figure 3.** Question A Pretest Versus Posttest Response (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree). N=22. Question A stated, "Your current level of familiarity with computers allows you to use one without apprehension."



**Figure 4.** Question B Pretest Versus Posttest Response (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree). N=22. Question B stated, "A mouse device is likely to be effective for controlling pitch and bank on a PC flight simulation software program."

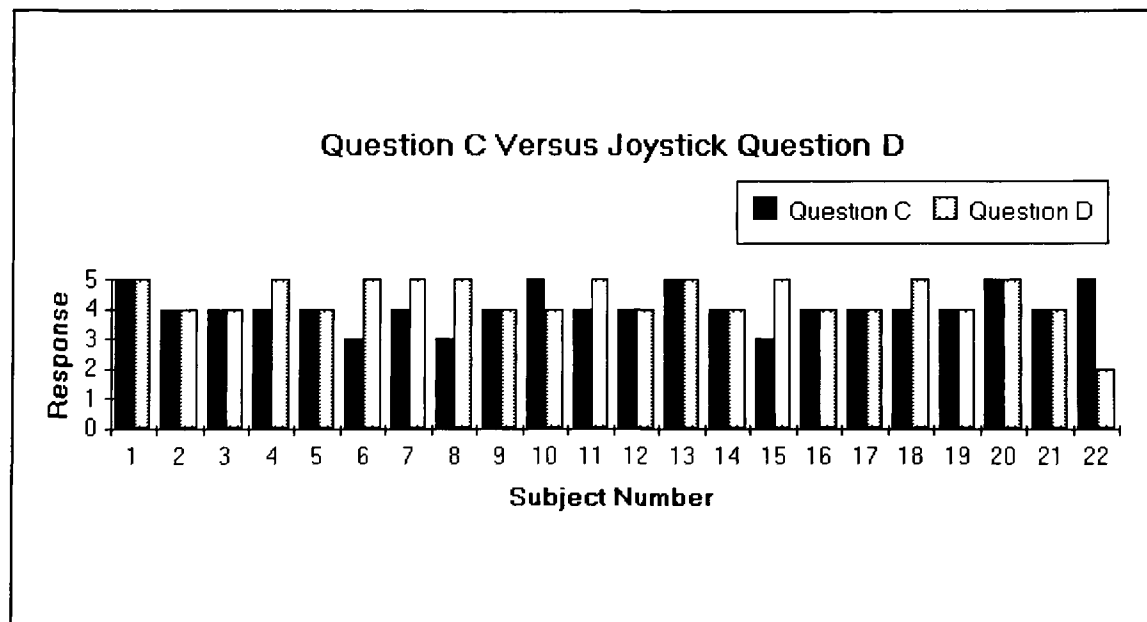
caused by the students' lack of experience with PC flight simulation software and associated control device capabilities. The experience gained during testing may have provided the added experience needed to more accurately respond to the question.

Questions C and D were very similar. Question C was included on the pretest questionnaire and stated, "The control yoke is likely to be effective for controlling pitch and bank on a PC flight simulation software program." Question D was included on the posttest questionnaire and stated, "The control yoke is effective for controlling pitch and bank on a PC flight simulation software program." The same questions were also asked in reference to the joystick device. Figure 5 compares the responses to these two questions for the control yoke device.



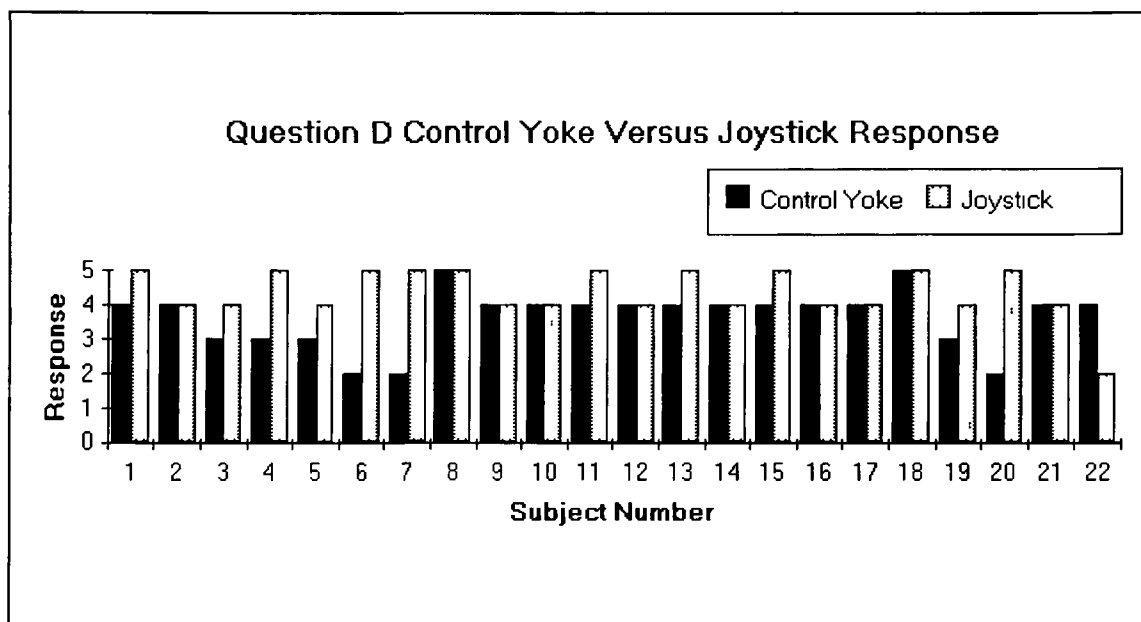
**Figure 5.** Question C Versus Control Yoke Question D (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree). N=22. Question C stated, "The control yoke is likely to be effective for controlling pitch and bank on a PC flight simulation software program." Question D stated, "The control yoke is effective for controlling pitch and bank on a PC flight simulation software program."

The intent was to provide an indication of student opinion variation caused by the testing. Eight students did not change their opinion, but 11 students degraded their opinion of the control yoke device performance between the time of pretest and posttest. This degraded opinion was similar to that which was reported for the mouse device. Figure 5 data was considered inconclusive until it was compared to the joystick device responses shown in Figure 6. Student opinion of the joystick device did not change in 13 cases, and improved in seven. Although according to the pretest each student thought the control yoke and joystick devices would likely perform very similar, the posttest results clearly indicated an improved opinion of the joystick device, and a degraded opinion of the control yoke device.



**Figure 6.** Question C Versus Joystick Question D (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree). N=22. Question C stated, "The joystick is likely to be effective for controlling pitch and bank on a PC flight simulation software program." Question D stated, "The joystick is effective for controlling pitch and bank on a PC flight simulation software program."

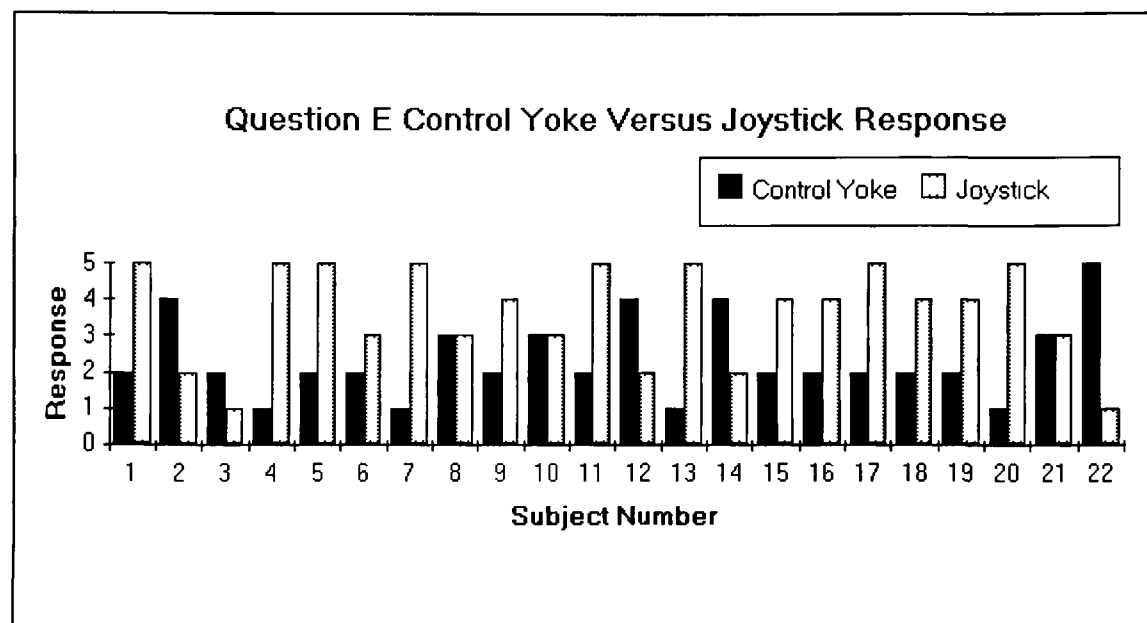
Figure 7 further supports the student's joystick device preference by showing a direct comparison of the control yoke question D and the joystick question D. Although ten student subjects rated both devices identical, 11 others indicated the joystick device was more effective for controlling pitch and bank than the control yoke device.



**Figure 7. Question D Control Yoke Versus Joystick Response (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree). N=22. Question D stated, "The control yoke/joystick is effective for controlling pitch and bank on a PC flight simulation software program."**

Question E was included only on the posttest questionnaire. The question stated, "The control yoke quickly became my preferred control device for use during general maneuvering." The same question was asked about the joystick device. Figure 8 shows a comparison of each student's control yoke device response with their joystick device response to this question. Three students rated both devices

identical, while 14 students indicated a preference for the joystick device by a wide margin. While this question indicates an opinion on no specific feature of each control device, the information is still important. Students using their preferred control device are likely to be more motivated to learn than when using a control device which, in their minds, is inferior. The joystick device was clearly preferred.

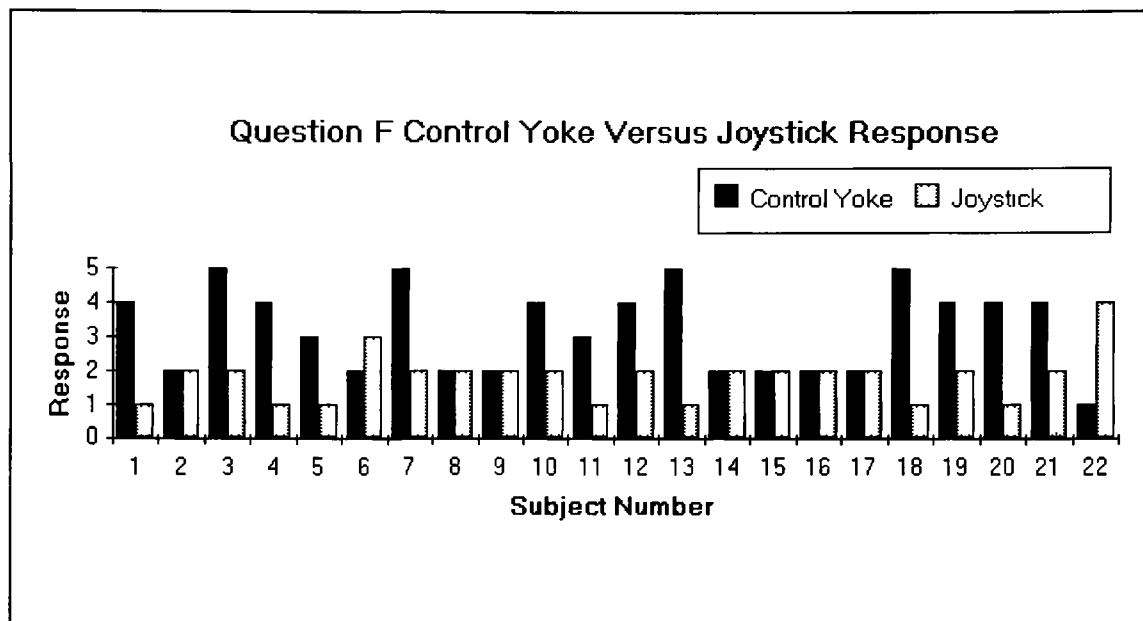


**Figure 8. Question E Control Yoke Versus Joystick Response (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree). N=22. Question E stated, "The control yoke/joystick quickly became my preferred control device for use during general maneuvering."**

Question F was included only on the posttest questionnaire. The question stated, "The control yoke made small pitch and bank adjustments difficult to perform." The same question was asked about the joystick device. Figure 9 shows a comparison of each student's control yoke device response with their joystick device response to this question. Seven students rated both devices identical, while 13

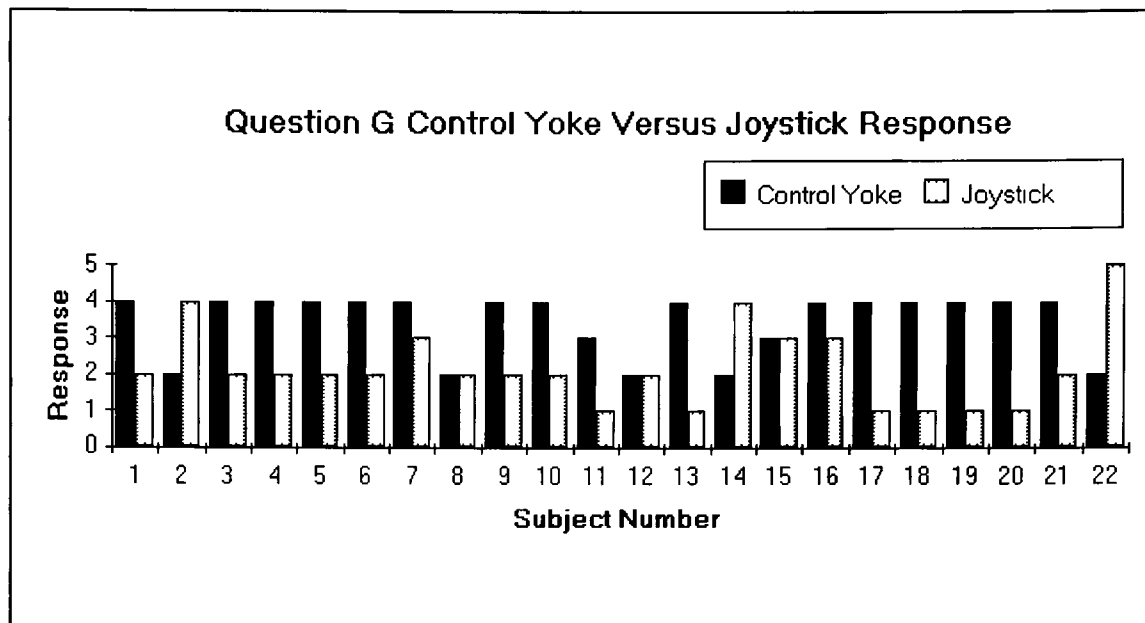


students indicated the control yoke device was more distracting than the joystick device by a wide margin. Once again, the joystick device was clearly preferred over the control yoke device.



**Figure 9. Question F Control Yoke Versus Joystick Response (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree). N=22. Question F stated, "The control yoke/joystick make small pitch and bank adjustments difficult to perform."**

Question G was included only on the posttest questionnaire. The question stated, "The control yoke on occasion became distracting because of its poor overall control feel." The same question was asked about the joystick device. Figure 10 shows a comparison of each student's control yoke device response with their joystick device response to this question. Three students rated both devices identical, while 16 students indicated the control yoke device had a poorer overall control feel than the joystick device by a wide margin. The joystick device was clearly preferred.

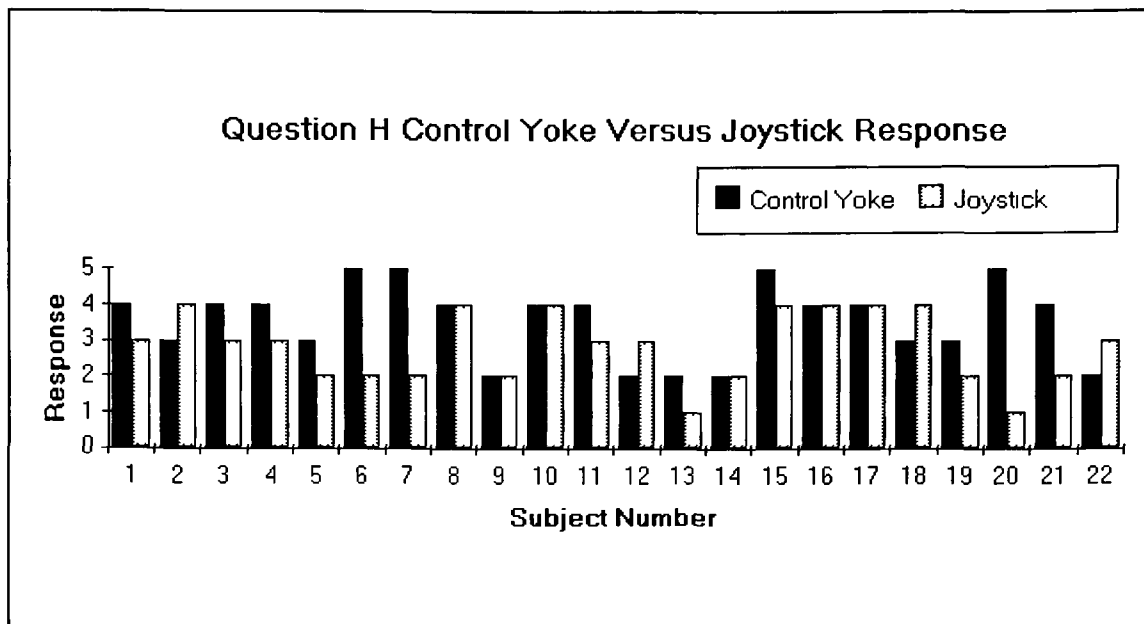


**Figure 10.** Question G Control Yoke Versus Joystick Response (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree). N=22. Question G stated, "The control yoke/joystick on occasion became distracting because of its poor overall control feel."

Question H was included only on the posttest questionnaire. The question stated, "The control yoke needs to provide a more realistic simulation of expected control pressures." The same question was asked about the joystick device.

Figure 11 shows a comparison of each student's control yoke device response with their joystick device response to this question. Six students rated both devices identical, while 12 students indicated the control yoke device simulated expected control pressures worse than the joystick device.

Every area of student subjective questioning showed persuasive favoritism for the joystick device when compared to the control yoke device. While this favoritism is only subjective, it still offers strong evidence that the students participating in this study were not disturbed by the joystick device's lesser physical fidelity.



**Figure 11.** Question H Control Yoke Versus Joystick Response (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree). N=22. Question H stated, "The control yoke/joystick needs to provide a more realistic simulation of expected control pressures."

The flight faculty postpractice questionnaire results (see Table 4) were similar to the student subject responses. While none of the questions received responses indicating unanimous favoritism for either control device, the joystick device did appear to be slightly preferred over the control yoke device. A few comments were made by the faculty volunteers which warrant consideration. One comment was that the joystick device's lack of physical fidelity should not be a hindrance to the training environment. This opinion is consistent with the results from the student testing. Another comment was that the joystick device seemed to have a neutral stability which was not as noticeable on the control yoke device. This opinion may be related to another comment which indicated the inherent advantage a wrist movement control device (the joystick) has over an arm movement control device (the control yoke).

Smoother control input may be possible with the joystick device, causing the sensation of a larger area of neutral stability.

**Table 4**

**Summary of Subjective Postpractice Faculty Responses**

Subject Number	Profile Letter	Device (see note)	Postpractice Question						
			A	B	D	E	F	G	H
1	A	CY	3	1	3	2	4	4	4
		JS			4	4	2	2	3
2	A	CY	4	2	3	3	3	3	4
		JS			4	1	2	2	2
3	A	CY	4	3	5	2	2	2	4
		JS			5	3	1	1	2
4	B	CY	1	1	4	2	2	2	4
		JS			4	3	1	2	4
5	B	CY	5	3	4	3	2	2	4
		JS			4	3	2	2	4
6	B	CY	5	3	4	2	2	2	2
		JS			4	3	4	3	5

Note. Device not applicable to questions A and B, Control Yoke (CY), Joystick (JS).

A = Your current level of familiarity with computers allows you to use one without apprehension.

B = A mouse device is likely to be effective for controlling pitch and bank on a PC flight simulation software program

D = The CY/JS is effective for controlling pitch and bank on a PC flight simulation software program.

E = The CY/JS quickly became my preferred control device for use during general maneuvering.

F = The CY/JS made small pitch and bank adjustments difficult to perform.

G = The CY/JS on occasion became distracting because of its poor overall control feel.

H = The CY/JS needs to provide a more realistic simulation of expected control pressures.

1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.

## CONCLUSIONS

The conclusions of this study were based upon subjective and objective data collected during controlled testing sessions. Final analysis of the objective data resulted in conclusions which did not support the hypothesis. Although the evidence was strong that both control devices performed exceptionally well, there were two out of eight flight control categories which indicated the joystick device significantly outperformed the control yoke device. Overall, the control devices did not perform as similar as expected. Results of the subjective questionnaires further supported the advantage a joystick device may have over a control yoke device during the demonstrated flight maneuvers.

As stated earlier, one result of these conclusions could have been that the joystick device exhibited significantly better performance than the control yoke device. Also, this result might be unexpected because of the comparatively inferior physical fidelity of the joystick device. Such a result would, however, keep system cost at a minimum, permitting easier acquisition by individuals and groups alike. Superior performance by the joystick device would also promote acceptance of the basic concept of PC training for its functional fidelity, and not for its limited physical fidelity. Each of these statements is supported by the testing results.

The joystick device exhibited significantly better performance than the control yoke device for pitch and bank control. Lesser physical fidelity of the joystick device

did not seem to affect its performance or popularity; personal computer ATD cost may be kept at a minimum; and the basic concept of PC training for its functional fidelity may be more easily accepted.

## **RECOMMENDATIONS**

Across the entire spectrum of flight training academies, universities, and fixed-based operations, personal computer ATDs are quickly being recognized as effective and versatile flight training tools. The extent of personal computer ATD effectiveness and versatility, however, is still open for discovery. Very little is known about the optimum combination of physical fidelity, functional fidelity, instructional method, and component attributes needed to provide an effective system for a given situation. Personal computer ATD versatility is similarly unexplored. Opportunities for evaluation of personal computer ATD systems and components seem endless.

This study evaluated only one aspect of one required feature of one type of ATD--the pitch and bank human and machine interface of a personal computer ATD. No attempt was made to evaluate other control actuators, visual displays, software attributes, or any other feature of the complete personal computer ATD. These other components can have a major impact on the ATD's overall effectiveness. For example, the NT360 control yoke and the Flightstick joystick have throttle actuators which are vastly different. The NT360's throttle is an easily adjusted push-pull knob which is very similar to many aircraft throttle controls. The Flightstick's throttle is a small disk which clicks as it is turned. Small throttle adjustments using the Flightstick are difficult to perform. Therefore, if this study included throttle control use, it is possible that student opinion of overall ATD control device performance

would have favored the NT360. Evaluation of all components of personal computer ATDs must be completed if the goal is to select appropriate training equipment. As advances in computer technology continue to provide new opportunities for ATD flight training, the need for complete system evaluation grows.

Evidence has been offered by this study that selection of one type of control device over another has an impact on a student's ability to perform basic flight maneuvers. But what effect does device selection have on more complex maneuvers? Does the performance difference affect transfer of training to the aircraft? Can a control device with much lower physical fidelity, such as a mouse, perform similar to the control yoke or joystick devices? Does the throttle control fidelity difference mentioned earlier have a significant effect on student opinion? These questions address areas of interest to flight training organizations. They are questions that need answers.

Collection of data which would provide those answers can be achieved through large scale training effectiveness research such as Hampton's (1993) study, ATD component comparison research such as this study, or individual component evaluation research. Results should be combined with other areas of personal computer ATD research to provide a foundation for widespread acceptance and application of relatively low cost, highly effective personal computer flight training.



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## **APPENDIX**

The appendices that follow have been included in this document for the purpose of providing more detailed information required by those individuals desiring to replicate any portion of this study. In most cases the appendix item is identical to the items used for actual testing. Minor adjustments were made in the appearance of each item so as to more easily include them in this printed document.

**APPENDIX A**  
**COVER LETTER**

### Cover Letter

Thank you for showing an interest in the personal computer flight control device comparison research being conducted at Embry-Riddle. There are several advantages to being selected as a participant in the study. First and foremost you will be supporting Embry-Riddle's efforts to provide cost effective alternatives to in-flight instruction. Second, you will become familiar with simulation equipment that is available for use at your convenience in the tutor lab. Third, your name will be included in the final research paper as a contributor. And fourth, extra credit may be offered by the ground training instructor for participation.

If selected, the entire process will be completed in one sitting, and should take less than an hour. You will receive a brief period of equipment practice, followed by a sequence of simple maneuvers using each control device. Immediately afterwards you will complete a short posttest questionnaire. All results will remain anonymous, and you will be placed under no pressure to "perform".

To be eligible for selection as a participant in the project you must fill out every section of the questionnaire on the other side of this paper. When finished you may either hand deliver this entire paper to Greg Fontaine (office D-215), leave it with the receptionist on the second floor of "D" building, or send it through campus mail (Greg Fontaine Flight Faculty).

Thank you again for your interest. If you would like more information about the project please feel free to stop by my office, or call.

**APPENDIX B**

**PRETEST QUESTIONNAIRE FOR STUDENT VOLUNTEERS**

**Pretest Questionnaire for Student Volunteers**

STUDENT NAME \_\_\_\_\_ BOX NUMBER \_\_\_\_\_ AGE \_\_\_\_\_

PRESENT FLIGHT COURSE \_\_\_\_\_ APPROXIMATE TOTAL FLIGHT TIME \_\_\_\_\_

(Check the box that applies.)

1. Have you received ground instruction which explained how to perform ILS approaches?	YES	NO
2. Have you performed an ILS approach in a reciprocating single engine aircraft.	YES	NO
3. Have you ever used a joystick device to control a personal computer flight simulation software program?	YES	NO
4. Have you ever used an aircraft-style control yoke device to control a personal computer flight simulation software program?	YES	NO
5. Have you ever used a mouse device to control a personal computer flight simulation software program?	YES	NO
6. Are you willing to put aside any preconceived ideas you may have about the control devices for the duration of the evaluation?	YES	NO

Strongly Disagree . 1

Disagree. . . . . 2

Neutral . . . . . 3

Agree . . . . . 4

Strongly Agree. . . . . 5

(Check the box that applies.)

7. Your current level of familiarity with personal computers allows you to use one without apprehension.	1	2	3	4	5
8. The joystick device is likely to be effective for controlling pitch and bank on a personal computer flight simulation software program.	1	2	3	4	5
9. The control yoke device is likely to be effective for controlling pitch and bank on a personal computer flight simulation software program.	1	2	3	4	5
10. The mouse device is likely to be effective for controlling pitch and bank on a personal computer flight simulation software program.	1	2	3	4	5



**APPENDIX C**  
**TESTING EQUIPMENT SETUP SHEET**

### **Testing Equipment Setup Sheet**

Start the computer and load the IFTP program. Select the Mooney (M20J) aircraft and the Daytona Beach International Airport for initialization data. Change the control panel variables to include the joystick device at level ten sensitivity. Change aircraft location to GF1. Location GF1 should place the aircraft directly over the Daytona Beach International Airport at 3,000 feet altitude, on heading 068 degrees, with gear up, propeller full forward, and manifold pressure at 23 inches. Location GF2 should place the aircraft on the Daytona Beach International Airport ILS, three miles outside the outer marker, at 1,600 feet altitude, on heading 068 degrees, with gear up, propeller full forward, and manifold pressure at 19 inches. The trim setting for both aircraft locations and configurations is neutral.

**APPENDIX D**  
**PROFILES A AND B**

### **Profiles A and B**

**Profile A practice session.** Set the student down at the testing area. Explain the general sequence of events and time table for the testing session. Inform the student that the purpose of the practice session is to become familiar with the testing equipment, and to establish a comfortable instrument crosscheck or scan. Point out the location of the airspeed indicator, attitude indicator, altimeter, turn coordinator, heading indicator, and vertical speed indicator on the computer monitor. Advise the student that all turns should be accomplished at standard rate, that trim will not be adjusted during the testing, and that all power adjustments will be made for them as the need arises. Also advise the student to perform the designated maneuvers using a comfortable level of concentration which can be maintained throughout the entire testing sequence.

The student is now ready for the practice session. Profile A students complete the practice sequence using the control yoke device, then the joystick device. Start the practice session for each control device from location GF1. The practice session maneuver sequence instructions are (a) maintain straight and level flight for ten seconds, (b) turn right from heading 068 degrees to heading 150 degrees, (c) turn left to 090 degrees, (d) pitch up ten degrees from level pitch attitude and hold it for two seconds, (e) pitch down to five degrees below level pitch attitude and hold it for five seconds, and (f) return to level pitch attitude.

**Profile A control yoke device testing session.** Change the aircraft location to GF1. Remove the simulator from "pause" mode, and instruct the student to maintain

altitude while turning left to a heading of 360 degrees. Wait until the turn is completed. Begin data collection using the data collection sheet while guiding the student step by step in accordance with the basic maneuver diagram. "Pause" the simulator and change aircraft location to GF2 at the indicated time. Remove the simulator from "pause" mode and complete the maneuver diagram and the data collection sheet.

**Profile A joystick device testing session.** Follow the exact procedure used during the control yoke device testing for the joystick device testing session.

**Profile A posttest questionnaire.** The posttest questionnaire should be annotated in the upper right corner with the student reference number and profile letter. Print the student's name and current date on the lines provided, and instruct the student to select an appropriate response for each of the questions that follow. The testing is now completed.

**Profile B.** One half of the students should be assigned Profile B. This profile is identical to Profile A with two exceptions. First, the practice session starts with the student using the joystick device, then switches to the control yoke device. Second, the joystick device testing session is conducted before the control yoke device testing session.

**APPENDIX E**

**DATA COLLECTION SHEET FOR STUDENT VOLUNTEERS**

### Data Collection Sheet for Student Volunteers

Student Reference No. \_\_\_\_ Control Device \_\_\_\_\_ Date \_\_\_\_ / \_\_\_\_ / \_\_\_\_ Start Time \_\_\_\_ Stop Time \_\_\_\_

Segment Number	Altitude (feet)	Heading (degrees)	Airspeed (knots)	Standard Rate Bank (degrees)	Rollout (degrees)	Pitch Attitude Variation (degrees)*
1	>200 200 150 100 50	>20 20 15 10 5				>20 20 15 10 5
2	>200 200 150 100 50			>20 20 15 10 5	>20 20 15 10 5	>20 20 15 10 5
3	>200 200 150 100 50	>20 20 15 10 5				>20 20 15 10 5
4	>200 200 150 100 50			>20 20 15 10 5	>20 20 15 10 5	>20 20 15 10 5
5	>200 200 150 100 50	>20 20 15 10 5				>20 20 15 10 5
6	>200 200 150 100 50			>20 20 15 10 5	>20 20 15 10 5	>20 20 15 10 5
7	>200 200 150 100 50	>20 20 15 10 5				
8	>200 200 150 100 50			>20 20 15 10 5	>20 20 15 10 5	>20 20 15 10 5
9	>200 200 150 100 50	>20 20 15 10 5				>20 20 15 10 5
10	>200 200 150 100 50			>20 20 15 10 5	>20 20 15 10 5	>20 20 15 10 5
11	>200 200 150 100 50	>20 20 15 10 5				>20 20 15 10 5
12		>20 20 15 10 5	>20 20 15 10 5			
13	>200 200 150 100 50	>20 20 15 10 5				
14	>200 200 150 100 50			>20 20 15 10 5	>20 20 15 10 5	>20 20 15 10 5
15	>200 200 150 100 50	>20 20 15 10 5				>20 20 15 10 5

Segment Number	Altitude (feet)	Localizer Course (deflection)	Glide Slope (deflection)	Pitch Attitude Variation (degrees)*
16	>200 200 150 100 50	FS <FS ¼ ½ ¼		>20 20 15 10 5
17		FS <FS ¼ ½ ¼	FS <FS ¼ ½ ¼	>20 20 15 10 5

\* Pitch attitude variation was measured from the highest to the lowest pitch attitude occurring during the largest single pitch oscillation in the segment.

**APPENDIX F**

**POSTTEST QUESTIONNAIRE FOR STUDENT VOLUNTEERS**



**Posttest Questionnaire for Student Volunteers**

STUDENT NAME: \_\_\_\_\_ DATE: \_\_\_\_\_

Strongly Disagree . 1  
 Disagree. . . . . 2  
 Neutral . . . . . 3  
 Agree . . . . . 4  
 Strongly Agree. . . . . 5

(Check the box that applies.)

1. The control yoke on occasion became distracting because of its poor overall control feel.	1	2	3	4	5
2. The joystick made small pitch and bank adjustments difficult to perform.	1	2	3	4	5
3. The control yoke needs to provide a more realistic simulation of expected control pressures.	1	2	3	4	5
4. The joystick quickly became my preferred control device for use during general maneuvering.	1	2	3	4	5
5. The joystick needs to provide a more realistic simulation of expected control pressures.	1	2	3	4	5
6. The control yoke quickly became my preferred control device for use during general maneuvering.	1	2	3	4	5
7. The control yoke made small pitch and bank adjustments difficult to perform.	1	2	3	4	5
8. The joystick on occasion became distracting because of its poor overall control feel.	1	2	3	4	5
9. The joystick is effective for controlling pitch and bank on a personal computer flight simulation software program.	1	2	3	4	5
10. The control yoke is effective for controlling pitch and bank on a personal computer flight simulation software program.	1	2	3	4	5
11. The mouse device is likely to be effective for controlling pitch and bank on a personal computer flight simulation software program.	1	2	3	4	5
12. Your current level of familiarity with personal computers allows you to use one without apprehension.	1	2	3	4	5

**APPENDIX G**

**POSTPRACTICE QUESTIONNAIRE FOR FACULTY VOLUNTEERS**

### Postpractice Questionnaire for Faculty Volunteers

FACULTY NAME: \_\_\_\_\_ DATE: \_\_\_\_\_

Strongly Disagree . 1  
 Disagree. . . . . 2  
 Neutral . . . . . 3  
 Agree . . . . . 4  
 Strongly Agree. . . . . 5

(Check the box that applies.)

1. The control yoke on occasion became distracting because of its poor overall control feel.	1	2	3	4	5
2. The joystick made small pitch and bank adjustments difficult to perform.	1	2	3	4	5
3. The control yoke needs to provide a more realistic simulation of expected control pressures.	1	2	3	4	5
4. The joystick quickly became my preferred control device for use during general maneuvering.	1	2	3	4	5
5. The joystick needs to provide a more realistic simulation of expected control pressures.	1	2	3	4	5
6. The control yoke quickly became my preferred control device for use during general maneuvering.	1	2	3	4	5
7. The control yoke made small pitch and bank adjustments difficult to perform.	1	2	3	4	5
8. The joystick on occasion became distracting because of its poor overall control feel.	1	2	3	4	5
9. The joystick is effective for controlling pitch and bank on a personal computer flight simulation software program.	1	2	3	4	5
10. The control yoke is effective for controlling pitch and bank on a personal computer flight simulation software program.	1	2	3	4	5
11. The mouse device is likely to be effective for controlling pitch and bank on a personal computer flight simulation software program.	1	2	3	4	5
12. Your current level of familiarity with personal computers allows you to use one without apprehension.	1	2	3	4	5

**APPENDIX H**  
**SUMMARY OF OBJECTIVE TEST DATA MEANS**

Summary of Objective Test Data Means

Subject Ref No	Profile Letter	Alt Var		Hdg Var		A/S Var		Bank Var		R/Out Var		Pitch Var		Loc Var		GS Var	
		CY	JS	CY	JS	CY	JS	CY	JS	CY	JS	CY	JS	CY	JS	CY	JS
4	A	50 00	53 33	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 83	6 79	5 00	0 25	0 25	1 00	0 25
6	A	50 00	50 00	5 00	5 00	5 00	5 00	8 33	5 00	5 00	5 00	8 21	5 36	0 25	0 25	0 25	0 25
8	A	50 00	50 00	5 00	5 00	5 00	5 00	8 33	5 83	5 83	5 83	5 71	5 71	0 25	0 25	0 50	0 25
9	A	50 00	50 00	5 00	5 00	10 00	5 00	8 33	5 00	5 00	5 00	8 21	5 00	0 38	0 25	0 50	0 25
10	A	50 00	50 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	6 07	5 00	0 25	0 25	0 50	0 25
11	A	50 00	50 00	5 00	5 00	5 00	5 00	5 83	5 00	5 00	5 00	7 14	5 36	0 25	0 25	0 50	0 25
13	A	53 33	50 00	5 00	5 00	5 00	5 00	5 00	5 00	5 83	5 00	6 79	5 36	0 25	0 25	0 25	0 25
15	A	53 33	50 00	5 00	5 00	5 00	5 00	5 83	5 00	5 00	5 00	9 29	6 79	0 25	0 25	0 25	0 25
16	A	50 00	50 00	5 00	5 00	15 00	5 00	9 17	5 00	5 00	5 00	8 21	6 07	0 38	0 25	0 50	0 50
20	A	53 33	50 00	5 00	5 00	5 00	5 00	6 67	5 83	5 00	5 00	6 79	5 36	0 25	0 25	0 50	0 25
22	A	50 00	53 33	5 00	5 00	5 00	5 00	6 67	5 00	5 00	7 50	10 00	8 93	0 38	0 50	0 50	0 50
Profile A Means		50 91	50 61	5 00	5 00	6 36	5 00	6 74	5 15	5 15	5 38	7 56	5 81	0 28	0 27	0 48	0 30
1	B	50 00	56 67	5 00	5 00	5 00	5 00	5 00	5 83	5 00	5 83	5 36	5 36	0 25	0 25	0 25	0 50
2	B	56 67	60 00	5 00	5 00	5 00	5 00	5 83	5 00	5 00	5 83	5 71	5 71	0 25	0 25	0 50	1 00
3	B	53 33	53 33	5 00	5 00	5 00	5 00	6 67	5 83	5 83	5 00	5 36	5 36	0 25	0 25	0 50	0 25
5	B	60 00	50 00	5 00	5 00	10 00	5 00	5 83	5 83	5 00	5 83	6 07	6 07	0 25	0 25	1 00	1 00
7	B	50 00	50 00	5 00	5 00	5 00	5 00	6 67	5 83	5 00	5 00	9 29	6 43	0 25	0 25	0 50	0 75
12	B	53 33	56 67	5 00	5 00	5 00	5 00	6 67	5 83	5 83	7 50	7 14	6 07	0 25	0 25	0 25	0 25
14	B	50 00	50 00	5 00	5 00	5 00	5 00	5 83	5 00	5 00	5 83	7 50	6 79	0 25	0 38	0 25	0 25
17	B	53 33	50 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	7 50	6 43	0 25	0 25	0 25	0 25
18	B	50 00	50 00	5 56	5 00	5 00	5 00	7 50	5 83	6 67	5 00	8 93	6 43	0 25	0 25	0 25	0 25
19	B	53 33	50 00	5 00	5 00	5 00	5 00	5 83	5 00	5 00	5 00	5 36	5 36	0 25	0 25	0 25	0 75
21	B	50 00	50 00	5 00	5 00	5 00	5 00	5 00	7 50	7 50	5 00	9 64	6 79	0 38	0 25	0 25	0 25
Profile B Means		52 73	52 42	5 05	5 00	5 45	5 00	5 98	5 68	5 53	5 53	7 08	6 07	0 26	0 26	0 39	0 50
Profile A/B Means		51 82	51 52	5 03	5 00	5 91	5 00	6 36	5 42	5 34	5 45	7 32	5 94	0 27	0 27	0 43	0 40

Note Control Yoke (CY), Joystick (JS) The means shown were calculated from individual student performance during execution of the appropriate maneuver profile